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March 15, 1965 STAT

SPECIFICATION

[redacted] TYPE 1032T TRICHROMATIC MICRODENSITOMETER STAT

1. GENERAL

[redacted] Trichromatic Microdensitometer is a unique data reduction instrument, a precision two-coordinate comparator combined with a very sensitive photometer. The digital output is not limited by or dependent upon the analog portions of the system. STAT

The ability to measure black and white photography to an optical density of 5 with 100 square microns effective scanning area at the emulsion, the very large total area that can be scanned, the ability to scan in two coordinates, automatic programming of the scan, simultaneous readout in density for three spectral regions, and high speed digital output to magnetic tape, all represent considerable improvement over any other microdensitometric system previously available.

With the [redacted] Trichromatic Microdensitometer, it is possible to reduce large amounts of high resolution spatial and spectral film or plates through the measurement of optical density at three wavelengths at precisely determined X, Y coordinates. The linear and optical density measurements are stored in digital form on magnetic tape. An analog output is also supplied by high quality strip chart recording. Scanning as fast as 125 mm/min. is possible with the digital output. The instrument is designed for routine, continuous operation with high reliability and simplicity of operation. The various necessary adjustments (such as for focus) are rapid and convenient for the operator. STAT

The instrument is shock mounted and is designed for optimum operation in an environment free from low frequency shocks or vibration below 10 cps. A clean, temperature and humidity controlled room is required. A temperature of $72^{\circ} \pm 1^{\circ}$F and a relative humidity of 50% $\pm$ 5% are considered satisfactory. The instrument should be free of drafts and temperature differentials induced by the air conditioning system. The air filters should reject all particles in excess of one micron in cross section, for the microdensitometry of very small areas would be influenced by dust particles.

The [redacted] Trichromatic Microdensitometer fulfills the functions of both a precision slit microdensitometer and a precision comparator. STAT

2. MECHANICAL

2.1 Scanning.

Both X and Y axes shall have both manual and automatic drive through motors. Ten discrete steps shall be provided in the range 0.125 mm/min. (minimum) to 125 mm/min. (maximum). There shall be no degradation in accuracy and performance at the highest speed. A programmable scanning action shall be provided (described later) for length of X scan and for step-over in Y (ΔY). Sampling interval in microns (ΔX) is also selectable from 1 to 999. To provide for reasonable tape utilization, the scanning speed in mm/min. divided by the sampling interval in microns shall be limited to 50 ($dx/dt \div \Delta X = 50$).

2.2 Precision Screw.

Travel along the axes shall be made by means of a precision screw with 1 mm lead and 1 mm pitch, mounted in superprecision ball-bearings. At the end of each screw there is a metal dial, graduated into one thousand divisions with a zero mark to permit reading one micron directly as least count, and a handwheel for use in adjustment and setup or for manually setting when the instrument is used only as a comparator. Safety limit switches and mechanical stops are provided for the precision screws. To warn the operator that there is a danger of mechanical interference with the stage, film transports, or plateholders, an electrical safety switch is provided around the lower microscope which cuts off drive power and sounds an alarm.

2.3 Measuring Stage.

The top stage is a rotary table which will permit manual rotation of material being scanned through 360 deg, although film transport devices can reduce this to ± 10 deg. The parallelism of the stage in its rotation and throughout its travel along the X and Y ways is held at a point underneath the optical system to within ± 0.0002 in. over the entire measuring area. When aligned with the ways, the top stage is available for scanning an area 10 in. in X by 4 in. in Y. This is with the plateholder and not with the manual or automatic film transport. With a film transport in place, the maximum scanning length will be less.

The cross slide ways are to be integral with the longitudinal slide and provide cross slide travel at right angles to the longitudinal slide to within ± 5 sec of arc.

Positional accuracy and repeatability shall be as described in a later section entitled, "Linear Measurement Accuracy."

2.4 Optional Film Transports.

2.4.1 Manual Transport. The transport shall accommodate 16 mm, 35 mm, and 70 mm films. The roll length accommodated shall be up to 500 ft. It shall have two speeds, one for quick search and one for accurate positioning. It shall be bi-directional.

2.4.2 Automatic Transport. The automatic film transport assembly shall accept 35 mm, 70 mm, and 100 mm perforated or unperforated film. It allows a rapid advance of the film to an area of interest by "Reel Drive." Through a velocity servo drive, the film can be advanced a "Single Frame" (a preselected distance) and by "Flow Motion" to achieve an accurate initial positioning of the film. A solid state electronic preset counter counts pulses from an optical shaft encoder coupled to a precise metering capstan. Film lengths of 0.25 in. to 9.0 in. can be metered in any multiple of 0.001 in. This makes frame advance independent of perforation.

The automatic film transport shall accept up to 500 ft. rolls of film, and the maximum area available for scanning with the device in position is 4 in. x 6 in.

2.5 Plate and Cut Film.

The instrument as supplied provides for the mounting of cut film and photographic plates.

2.6 Linear Measurement Accuracy.

Exclusive of the quality of the image being read and human error, the overall accuracy of the instrument shall be as follows:

The actual stage position at any millimeter interval in its travel shall not deviate by more than 1 micron or 0.001% of the travel, whichever is greater. Backlash is the result of the connection between the precision nut and the stages. It shall be compensated by the digital shaft encoder head drive system so as to appear backlash free when digitized readout is used. The instrument shall be calibrated at 68°F, the international standard.

2.6 Floor Stand.

The base of this instrument shall consist of a heavy well-ribbed Meehanite casting used as a comparator base. The slides and the optical system support casting (overarm) shall be designed for stability in the direction of focus which is more critical here than on a measuring comparator. All slides shall be of cast Meehanite normalized during machining operations to relieve stresses. Base, overarm, and pickup microscope assemblies in turn shall be carefully fitted to a heavy ribbed Meehanite plate. To this plate shall be fastened the various drives for the X and Y axes. The plate shall be supported on vibration isolators between it and the heavy sheet steel supporting console which carries the operator's controls that need to be directly at the densitometer. The entire instrument shall be supported on three adjustable leveling pads at floor level.

3. OPTICAL

3.1 Illumination System.

Illumination shall be supplied by a low-voltage tungsten source the spectral characteristics of which can be altered by filter insertion. The illuminating optics shall be microscope objectives. Coarse and fine focus adjustment shall be furnished. The focus shall be adjusted by means of remote control such that the operator can watch the focus through the observation microscope below the stage while focusing. Objective lenses supplied shall give approximate reductions of 7X, 9X, 16.5X, 20.5X. Capability for projection either by circular apertures, or by conventional fixed or dual bilaterally adjustable illuminating slits, shall be built into the optical system.

The illumination system shall be mounted in the overarm with special attention to vibration-free air cooling. All illuminating objectives shall be mounted in special centering objective mounts so that they may be carefully adjusted by viewing from the observation microscope inserted into the pickup optical system to have the same collimation for which the instrument is initially adjusted. They shall be removed and replaced accurately and quickly.

3.2 Pickup System.

The pickup optical system shall be mounted from the bottom so as to have the greatest possible convenience in setting up material to be scanned. It shall use interchangeable microscope objectives to give emulsion magnifications of approximately 7X, 9X, 16.5X, and 20.5X. The microscope shall have coarse and fine focus adjustments. Provision shall be made for focusing the illuminating spot of light at the emulsion. This shall be accomplished by use of a retractable microscope system which may be inserted into the pickup system optical path. This observation microscope shall be provided with a light attenuator to adjust brightness for operator comfort. The ocular views a reference cross hair which can be used in alignment checks and in distance measurements. The microscope shall provide sufficient magnification for precise alignment of images to be scanned. The microscope shall be held in the viewing position by a magnetic lock assembly. An electrical interlock shall be provided to prevent operation of digital readout while the microscope is in the optical path. A mount at the termination of the pickup optics shall provide for the mounting of fixed exit or scanning slits with white upper surface to form a viewing screen. This assembly may be replaced by a dual bilateral adjustable slit system.

Beneath the scanning slit is positioned a compound Fabry lens which focuses the exit pupil of the pickup objective onto the photomultiplier tubes, eliminating the possibility for wander on the photosensitive surface.

Facility is provided for placing a dark slide and clear aperture in the light path between the Fabry lens and each photomultiplier tube. Provision is also made for placement in the light path of a series of six attenuation filters before each detector. These shall have nominal values of 0, 0.5, 1, 2, 3 and 4 density.

3.3 Chromatic Microdensitometry.

This instrument shall provide three independent photometers with three high gain selected photomultiplier tubes operating from a single optical path at the plate. In this manner, simultaneous reading of optical density at three wavelength bands is possible. This insures that all three color density records will be made at positively the same spot on the emulsion and removes the necessity for three independent, time consuming scans of the sample and reliance on mechanical-electronic means to insure that all the readouts in the three colors are at the same X, Y positions that were predetermined. The photometers shall be adjustable for equivalent outputs in terms of optical density.

A trichromatic instrument is realized through the use of chromatic beam splitters and filters which shall be arranged so as to direct the proper color of light to each of three photomultiplier tubes simultaneously. These beam splitters and filters will be of the multilayer type. The wavelength of the peak and the half width of the response is specified by the user according to his requirements. Typically, a peak will fall in the red, blue, and green regions of the spectrum with half widths of approximately 50 microns. It shall also be possible to use one photomultiplier tube alone for ordinary monochromatic microdensitometry.

3.4 Substage Illuminator.

Beneath the film transport or plateholder shall be mounted two 4-watt fluorescent lights which may be turned on to act as general field illuminators. This shall permit rapid determination of the area of interest and permit bringing it very close to the optical axis so that the observation microscope system may then be used for a precise alignment in setting up the area to be scanned.

3.5 Auxiliary Field Illuminator.

As an additional aid in finding a point of interest, a light source can be introduced between the illuminating slit and the illuminating objective which may be turned on to illuminate the area in the focal plane of the illuminating objective. This feature, when used with the Substage Illuminator of 3.4, shall bring the point of interest rapidly to the optical axis where final adjustment is made with the observation microscope.

3.6 Slits (Apertures)

3.6.1 Illuminating Apertures. The chief function of the entrance aperture is to minimize off-axis scattered light. The illuminating aperture is slightly larger than the scanning aperture (in equivalent terms at the emulsion surface). Provision will be made for utilizing illuminating apertures of both the fixed and the bilaterally adjustable type.

3.6.2 Scanning Apertures. The defining aperture for microdensitometry shall be provided by the scanning slit located at the focal plane of the pickup microscope objective. The slit jaws upper surfaces are painted white to form a viewing screen to permit operator monitoring of what is being scanned.

3.6.3 Filter Glass Jaws for Illuminating Slit. Not included in this specification, but available from the [redacted] are illuminating STAT slits with jaws made of green filter glass. These give a pleasant surrounding field to the area being scanned. When these are used, a filter is inserted before the photomultipler tube to cancel the green light, making the jaws appear virtually opaque to the detector. This feature cannot be used for trichromatic densitometry but only monochromatic.

3.7 Accessory Box.

A wooden case, padded inside, shall be furnished for storage of the film stage, slit assemblies, lenses, small adjustment tools, spare bulbs, etc.

4. AUTOMATIC SCANNING PROGRAM

The microdensitometer shall be capable of scanning in either the X or Y coordinates. Length of scan shall be controlled by adjustable micro-switches. Stepover between successive scans shall be counter controlled and variable from 0.001 mm to 9.999 mm in steps of 1 micron. When stepover is changed from one axis to the other, the counter shall be switched to the proper axis. Minimum length of scan shall be approximately 6 mm. Maximum length of scan will be limited by either the film stage or the plateholder. Safety limit switches and mechanical stops shall be provided for the precision screws. To warn the operator that there is a danger of mechanical interference with the stage film transports or plateholders, an electrical safety switch shall be provided around the lower microscope which cuts off drive power and sounds an alarm.

In particular, the following scanning action or raster scan shall be provided: Scanning forward in X, counter-programmed step in Y, scanning backward in X, counter-programmed step in Y, scanning forward in X, and so on.

In addition, the scan axis shall have a bidirectional counter in order to achieve a variable spatial resolution for the digital readout. The range shall be from 1 micron to 999 microns in steps of 1 micron. During the stepover operation, no readout shall occur.

5. ANALOG READOUT

5.1 Photomultiplier Detectors.

The detectors shall be selected high gain photomultiplier tubes. Suitable infrared filtering shall be used in the system to prevent local intensification of thermionic emission of the photocathodes. The assembly containing the socket, tube, and dynode resistors shall comprise a single light-tight unit (except for the entrance window). When in position in the instrument, the photomultiplier tube assemblies shall be light tight except to the measuring light beam when the shutter is opened beneath the scanning slit. The tube mounts shall provide for the adjustment of tube rotation and position of the photosensitive surface along the optical axis of the instrument if needed.

5.2 Fabry Lens and Filters.

A compound Fabry lens system shall be positioned beneath the scanning slit to focus the exit pupil of the pickup objective onto the photosensitive surfaces. The purpose of these lenses shall be to minimize the effects of room illumination and to fix the position of the illuminating spot on the photosensitive surfaces.

Provision for inserting as many as three filters in the illuminating optical path shall be provided.

5.3 Photometric Amplifier.

The photometric amplifier associated with each photomultiplier tube shall amplify the signals of the photomultiplier tube, and the operator shall have a choice of either a linear or logarithmic characteristic. In the logarithmic mode, this instrument shall read density, defined as $\log \frac{1}{T}$, where T is the transmittance measured by this instrument. After sufficient warmup (approximately 1/2 hour), the instrument shall be stable in logarithmic mode to 0.01 density units over an eight-hour period in a normal operating situation (effective illuminating slit size being larger than the effective scanning slit size in both dimensions by approximately two microns). This test is made by observing zero density stability on the strip chart recorder. No unusual air currents, temperature variations, or vibrations can be allowed during this test.

The linear mode shall have six ranges of amplification, and when operating in the linear mode, a protective circuit shall prevent the photomultiplier tube from overexposure with too high a voltage across the dynodes.

Controls shall be provided for setting the 100% transmittance point for the light available with various slit and lens combinations. The amplification ranges shall provide scale expansions.

In the linear mode, the stability after 1/2 hour warmup shall match the performance of the instrument in the logarithmic mode under similar operating conditions. The test shall be the observance of 100% transmittance stability over an eight-hour period. It shall be realized that very high gain in the linear mode also gives high gain to normal thermionic emission noise and statistical noise of the photomultiplier tube.

5.4 Frequency Response.

The frequency response of the amplifier shall be sufficiently flat to permit use of the highest scan speed without deterioration of 2.5 micron resolution or the density reading level with digital readout. It is understood that the time constant of the analog readout will limit scan speed to the slowest scan speeds available.

5.5 Sensitivity.

The monochromatic photometric system shall be capable of reading in excess of density 5.0 with a scanning slit area of 100 square microns. Densities as great as 6.0 shall be achieved with sufficiently large scanning area. It is understood that proper lens combinations will be required for maximum sensitivity. Densities in excess of 4.0 may not be obtainable for chromatic microdensitometry without enlarged scanning area.

5.6 Strip Chart Recorder.

Two Moseley 7100 AR two pen strip chart recorders shall be supplied. One shall carry two channels and the second recorder the third channel. The recorder shall have a response time for full scale as good as, or better than, 0.4 sec. Chart speeds shall be variable in steps from 0.1 in/sec. to 2 in/hr., and the change in chart speed shall be possible without the necessity for removing and altering gear arrangements. The recorders shall operate simultaneously with the digitizer, but the recorder can be time constant limited at higher scanning rates. When used with trichromatic output, synchronizing marks will be made at the edges of the charts.

5.7 Regulated Power Supplies.

The regulated power supply for the illuminating lamp is included in the amplifier chassis. Also, the power supply for the photomultiplier tube is a part of the amplifier chassis.

6. PHOTOMETER PERFORMANCE SPECIFICATIONS

6.1 Resolution.

With lenses of numerical aperture 0.25 and appropriately selected scanning apertures, the instrument shall demonstrate a practical resolution of 2.5 microns. The resolution test consists of scanning a photographic high-contrast three-bar resolution target of 228 line pairs per millimeter (equal black and clear spaces).

6.2 Density Range. (Sensitivity)

The instrument shall be capable of reaching a density of 5.0 with a scanning area at the emulsion surface of 100 square microns. This range will be reduced to approximately 4.0 when chromatic microdensitometry is employed. Density is as defined in 5.3. The specification applies when optimum lens combinations are used. It is anticipated that the room will have to be darkened for reading accurately the densities at the high end of the range.

6.3 Scattered Light.

The instrument shall be engineered to realize the maximum possible elimination of scattered light. The internal metal parts of the objectives shall be blackened. The objectives shall be anti-reflection coated. Baffles shall be inserted in the illuminating system at critical positions to minimize scattering. Critical scattered light tests cannot be made with full room illumination. Evaluation of edge tests should show the specified resolution unimpaired by the low level of scattered light present.

6.4 Reproducibility.

The reproducibility of the instrument is $\pm$ 0.01 in density for density in the range of 0 to 1 and 1% for density in the range of 1 to 5. Scanning speeds shall not be so fast that recorder response time influences this test.

7. POWER REQUIRED

The instrument and associated recording equipment shall be designed to operate from standard 60 cycle/second, single phase power, 117V AC. The equipment shall operate to specifications within normal power fluctuations (105 to 125 volts). Total power required does not exceed 4 KVA.

8. TEST DEVICES

The following devices shall be furnished for maintaining the instrument calibration:

a. A Precision Linear Scale, [redacted] Type B, may be used to check the comparator portion of the instrument. STAT

b. One set of Specular Density Filters, enabling an approximate optical density range of 0.1 to 4.0. These filters are used for establishing and maintaining the photometric calibration.

c. A machine scan resolution test target which will enable observation of resolution capabilities with various optical and scanning parameters.

9. DIGITAL READOUT SYSTEM

9.1 General.

The digital readout system shall generate from signals supplied by other portions of the microdensitometer digital data indicating image density and the X and Y coordinates of stage position and shall store these data on magnetic tape. The recording shall be in IBM format as described under 9.4.1, Output Format.

In the principal mode of operation, a film will be scanned automatically at rates up to 125 millimeters per minute. Trichromatic density measurements shall be made at regular intervals along each scan line as selected by the operator. These measurements together with the X and Y coordinates of the beginning and end of the line shall be recorded automatically in digital form on magnetic tape. Provision shall also be made for similar recording of ordinary density with black and white film. In addition, provision shall be made for recording parametric data inserted by the operator.

In the second mode of operation, digital values of X and Y and a single reading of density shall be recorded on command from an operator.

9.2 Major Components.

The digital readout system shall consist of the following major components:

a. two [redacted] data heads, STAT
b. X and Y counters,
c. multiplexer and analog-to-digital converter,
d. buffer and recorder,
e. control panel, power supplier, cables, etc., as required.

These components may be integrated into a single system and need not be physically separable.

9.3 Detailed Provisions.

9.3.1 Coordinate Inputs. The system shall utilize as input data for coordinate measurements pulses from [redacted] data heads. One head shall STAT be driven by the precision screw for each axis and shall furnish a pulse for each micron of stage travel.

9.3.2 X and Y Counters. An 18-bit reversible binary counter shall be used for each axis, which counter shall maintain an exact count indicating stage position as the stage is moved back and forth along its ways. Provision shall be made for resetting both counters.

A visual display of counter state shall be provided.

9.3.3 Photometric Input. The photometric digitizing system shall utilize as inputs direct voltages from the three photometer amplifiers, accepting either logarithmic or linear output as selected by the operator. The system shall utilize the voltage from only one of these amplifiers when reading black and white film. The scale of these voltages shall be 0 to 10 volts.

9.3.4 Multiplexer and Analog-to-Digital Converter. At regular selected intervals along the scan line, as determined by the interval counter in the automatic scanning program circuits, the multiplexer shall sample the three density input voltages and shall feed these samples in sequence to the analog-to-digital converter. The converter shall convert each of the samples to a 10-bit binary number.

The accuracy of conversion referred to the input voltage, with static or slowly varying input voltages, shall be at least ± 0.010 volts including quantizing error.

The converter shall provide a visual display of the binary number. It shall also furnish electrical outputs to allow recording digital values of density as described below.

Provision shall be made for digitizing each photometer individually to permit using the converter as a voltmeter when making calibration adjustments.

9.4 Buffer and Recorder.

This unit shall contain a typewriter as an input writer, a magnetic core buffer, a magnetic tape recorder, and the control circuits for storage and recording of the data.

9.4.1 Output Format. The magnetic tape shall be recorded at a density of 556 characters per inch in the IBM 729 IV tape format (load point, record gap, end of file mark, lateral parity bit, longitudinal parity, tape width, tape reel, etc.). For the principal scanning mode, provision shall be made for recording one file for each frame of film. The file shall consist of a parametric data record, information records, and an end of file mark.

The parametric data record shall contain any number of alphanumeric characters up to 72, inserted by the operator using the input writer. Additional blank characters shall be inserted automatically to make a total of 72 characters (lines) in the record.

Each information record except the last in a file shall contain 90 words of 48 bits each. The first word of the first information record, called a coordinate word, shall contain the values of X and Y for the beginning of the first scan line. Each of the following words, called density words, shall contain the three values of trichromatic density at the programmed intervals along the scan line, with one density word for each interval. The density readings shall continue through this record and into the following records if necessary until the scan line is completed. A coordinate word containing the X and Y coordinates of the end of the line shall then be recorded. Continuing with the same record, unless it was exactly filled on the first scan line, coordinate values for the beginning and end of each scan line and density readings throughout each line shall follow in the same form until the raster is completed. On command from the operator, the last record shall be recorded followed by an end of file mark. The last record shall always contain an integral number of 48-bit words but may contain fewer than 90 words.

When scanning black and white film, one density word shall be recorded for each three scan interval, and it shall contain the three density values for these intervals. If the number of intervals in a scan line is not a multiple of three, zeros, or dummy values of density, suitably tagged, shall be inserted to complete the density word. In other respects, the format shall be at the same as for color film.

The number of density readings recorded shall provide an accurate count of intervals scanned to allow the computer to accumulate the value of the coordinate being scanned. The coordinates recorded for the end of scan line shall provide a check of the accumulated coordinate value.

9.4.2 Circuits. A magnetic core buffer shall be used to accommodate the difference between the input and recording data rates. The digital data shall be stored in the buffer, and when a full record of 90 words is stored, the tape recorder shall be started and this record written on the magnetic tape. The buffer shall be capable of interlace operation so as to accept incoming data while recording on tape. Provision shall be made to terminate the last record of a file at less than 90 words.

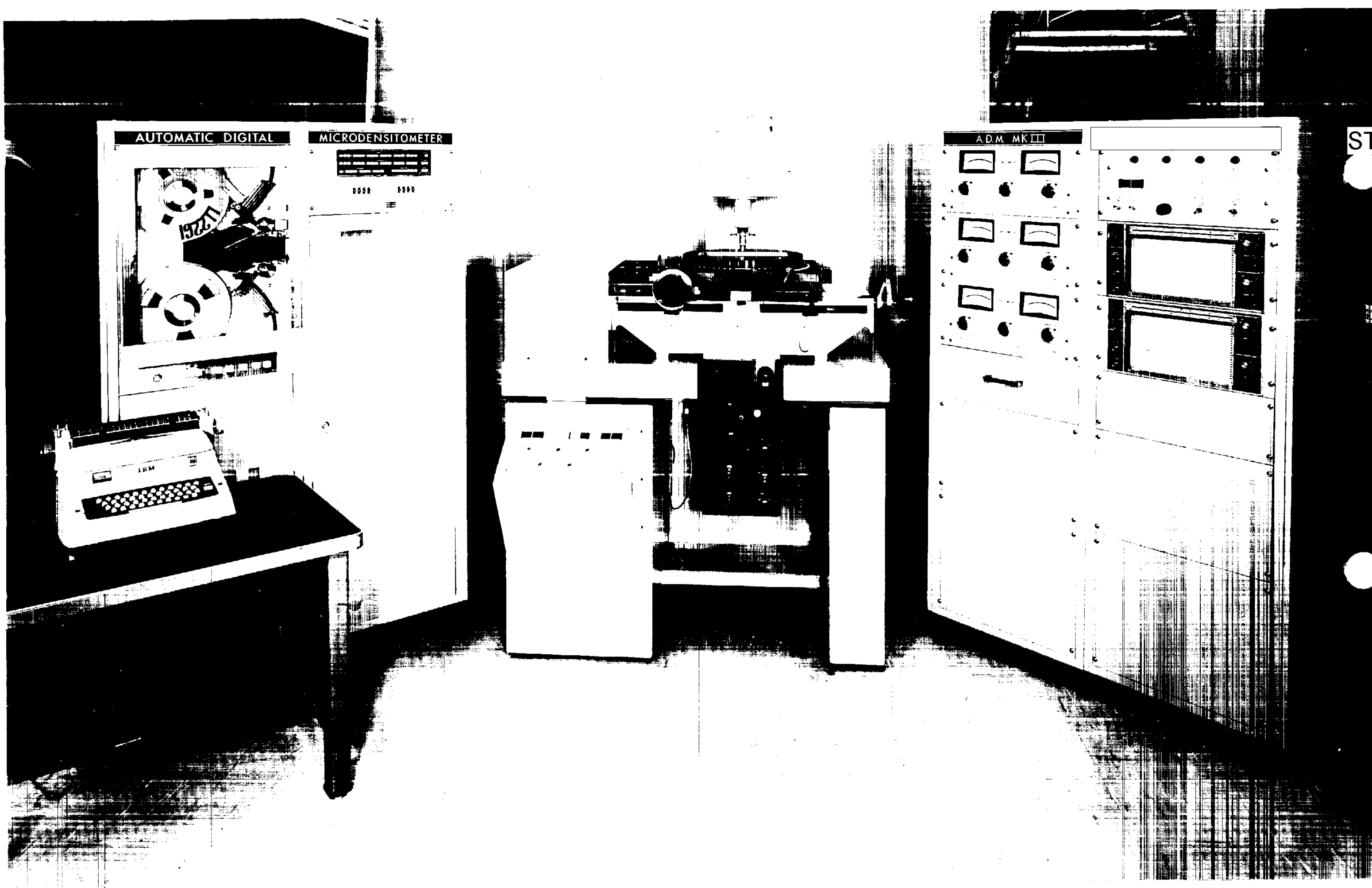
The head dimensions for the tape recorder shall be compatible with IBM 729 IV format. The recorder shall be capable of starting and stopping in 10 MS or less under control of the associated circuits. The tape speed shall be such that the highest data rates expected can be recorded in the prescribed format. Sensors for load point and end of tape markers shall be included. Tape positioning to the load point shall be automatic. The recorder shall have both write and read heads. Provision shall be made for viewing the output of the read head, one channel at a time, using an oscilloscope--not furnished.

A typewriter shall be provided for inserting parametric data. It shall have keys for digits 0-9, letters A-Z, signs and control functions. The characters stored shall be printed on paper as a check for the operator.

9.4.3 Manual Readout Controls. Controls shall be provided for manually disabling and for overriding the automatic control circuits. Provision shall also be made for disabling these circuits during appropriate portions of the automatic scanning program.

An additional control shall be provided for reading out fixed points. Each time this control is operated, a coordinate word, a density word, and another coordinate word, shall be stored in the buffer. On command, one or more of these readings in the buffer then shall be recorded on tape in a short record.

A control shall be provided to clear the buffer without recording on tape.



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